

TEST Λ CDM MODEL WITH HIGH REDSHIFT DATA FROM BARYON ACOUSTIC OSCILLATIONSYAZHOU HU^{1,2}, MIAO LI^{3,1}, ZHENHUI ZHANG^{1,2}*Draft version January 5, 2015*

ABSTRACT

The Baryon Acoustic Oscillations (BAO) provide a standard ruler for studying cosmic expansion. The recent observations of BAO in SDSS DR9 and DR11 take measurements of $H(z)$ at several different redshifts. It is argued that the behavior of dark energy could be constrained more effectively by adding high-redshift Hubble parameter data, such as the SDSS DR11 measurement of $H(z) = 222 \pm 7$ km/sec/Mpc at $z = 2.34$. In this paper, we investigate the significance of these BAO data in the flat Λ CDM model, by combining them with the recent observational data of the Hubble constant from local distance ladder and the Cosmic Microwave Background (CMB) measurements from Planck+WP. We perform a detailed data analysis on these datasets and find that the recent observations of BAO in SDSS DR9 and DR11 have considerable tension with the Planck + WP measurements in the framework of the standard Λ CDM model. The fitting results show that the main contribution to the tension comes from the Hubble parameter measurement at redshift of $z = 2.34$. But there is no visible tension once the joint data analysis by combining the datasets of SDSS and Planck+WP is performed. Thus in order to see whether dark energy does evolve, we need more independent measurements of the Hubble parameter at high redshifts.

Subject headings: expansion history — cosmology: observations — methods: statistical

1. INTRODUCTION

The cosmic acceleration was discovered in 1998 (Riess et al. 1998; Perlmutter et al. 1999), and it has been confirmed by several independent observations. The standard Λ CDM model provides a succinct description of the cosmic acceleration matching current Cosmic Microwave Background (CMB) observations (Planck XVI 2013). Besides the CMB measurements, the Baryon Acoustic Oscillation (BAO) measurements are recognized as robust and independent probes of cosmology, since they provide a standard ruler for studying the cosmic expansion. Recently, Delubac et al. (2014) reported a detection of the BAO feature in the flux-correlation function of the Ly α of high-redshift quasars from the Data Release 11 (DR11) of the Baryon Oscillation Spectroscopic Survey (BOSS) (Dawson et al. 2013) of SDSS-III (Eisenstein et al. 2011). By adopting the value of sound horizon at the drag epoch $r_d = 147.4$ Mpc from the Planck+WP fitting of the concordance cosmology, Delubac et al. (2014) derive a high-redshift Hubble parameter $H(z = 2.34) = 222 \pm 7$ km/sec/Mpc. As the measurements of $H(z)$ parameter at different redshifts are statistically independent, they are suitable for studying the evolution of the cosmic geometry. With these high-redshift $H(z)$ data, Sahni et al. (2014) test the cosmological constant hypothesis by employing the evolution of $H(z)$ according to the recent observations of BAO's in SDSS DR9 (Samushia et al. 2013) and DR11

(Delubac et al. 2014). By adopting an improved version of the Om diagnostic, Sahni et al. (2014) find that there is considerable tension with the Planck+WP measurements in the framework of the standard Λ CDM model. By the Om diagnostic, the $Om h^2$ value is independent of the redshift if dark energy is a constant. However, they find that $Om(z = 2.34)h^2 = 0.122 \pm 0.01$, while the Planck result is $Om h^2 = 0.1426 \pm 0.0025$ (Planck XVI 2013). Therefore, the Λ CDM model is in conflict with the Hubble parameter measurement at redshift $z = 2.34$, at the level of two standard deviation.

In this paper, we investigate this tension through joint data analysis instead of the $Om h^2$ diagnostic, in order to compare the significance of these high-redshift BAO data with that of the Planck data.

2. METHODOLOGY & RESULTS

For comparison, we use the same $H(z)$ dataset of (Sahni et al. 2014), including the Hubble constant from local distance ladder ($H(z = 0) = 70.6 \pm 3.2$ km/sec/Mpc (Efsthathiou 2014)), the Hubble parameter from anisotropic clustering of SDSS DR9 ($H(z = 0.57) = 92.4 \pm 4.5$ km/sec/Mpc (Reid et al. 2012)) and the new $H(z)$ data from the Ly α forest of SDSS DR11 quasars ($H(z) = 222 \pm 7$ km/sec/Mpc at $z = 2.34$ (Delubac et al. 2014)).

As we noted above, the high-redshift Hubble parameter $H(z = 2.34)$ is derived by scaling at a r_d from the Planck+WP measurements, so the value of $H(z = 2.34)$ is correlated with the Planck+WP dataset. To avoid this correlation, we also adopt the most precisely determined combination from (Delubac et al. 2014), namely

$$\alpha_{\parallel}^{0.7} \alpha_{\perp}^{0.3} = 1.025 \pm 0.021, \quad (1)$$

where α_{\parallel} and α_{\perp} are defined as

$$\alpha_{\parallel} = \frac{[D_H(\bar{z})/r_d]}{[D_H(\bar{z})/r_d]_{\text{fid}}} \quad \text{and} \quad \alpha_{\perp} = \frac{[D_A(\bar{z})/r_d]}{[D_A(\bar{z})/r_d]_{\text{fid}}}, \quad (2)$$

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where the fiducial values $[D_H(\bar{z})/r_d]_{\text{fid}}$ and $[D_A(\bar{z})/r_d]_{\text{fid}}$ at $\bar{z} = 2.34$ are 8.708 and 11.59 respectively. For the SDSS DR9 dataset, the result that $D_V(0.57)/r_s(z_d) = 13.67 \pm 0.22$ obtained by Anderson et al. (2012) will be used. For a further comparison, we also employ the improved $D_V/r_s(z_d)$ measurements of SDSS DR11 dataset, which gives $D_V(z = 0.32)/r_s(z_d) = 8.25 \pm 0.17$ and $D_V(z = 0.57)/r_s(z_d) = 13.42 \pm 0.13$ (Anderson et al. 2013) respectively.

In the following context, we will use “H0”, “Hz”, “DR9”, “DR11”, “DR11Ly α ”, and “Planck+WP” to represent the Hubble constant, the three $H(z)$ data, $D_V(0.57)/r_s(z_d)$ of SDSS DR9, $D_V(0.32)/r_s(z_d)$ and $D_V(0.57)/r_s(z_d)$ of SDSS DR11, $\alpha_{\parallel}^{0.7}\alpha_{\perp}^{0.3}$ of SDSS DR11 at redshift $z = 2.34$ and the Planck+WP dataset respectively. For convenience, we will use “SDSS” to represent the combination of “Hz”, “DR9”, “DR11” and “DR11Ly α ” datasets.

With these datasets, we perform χ^2 analysis and explore the parameter space using Markov Chain Monte Carlo (MCMC) algorithm by modifying the CosmoMC package (Lewis & Bridle 2002).

Table 1 and Table 2 summarize the fitting results of the parameter constraints (the 68% CL limits) and corresponding χ^2_{min} 's. In Figure 1, in order to make a comparison, we plot the likelihood distributions of $\Omega_m h^2$ with two different selections: the Hz and Planck+WP datasets (corresponding the upper panel); the DR9, DR11 and Planck+WP datasets (corresponding the below panel).

Sahni et al. (2014) show that the estimation of the new diagnostic $Om h^2$ from SDSS DR9 and DR11 data gives $\Omega_m h^2 \approx 0.122 \pm 0.01$, having tension with the value $\Omega_{0m} h^2 = 0.1426 \pm 0.0025$ determined for Λ CDM from Planck+WP at over 2σ . From Table 1 and the upper panel of Figure 1, we can see that the Hz and the Planck+WP give constraints $\Omega_m h^2 = 0.1221 \pm 0.0085$ and $\Omega_m h^2 = 0.1426 \pm 0.0025$ respectively, which means the Hz dataset does have tension with the Planck+WP dataset at over 2σ . However, when using the Hz+Planck+WP and H0+H($z=0.57$)+Planck+WP datasets, the constraints are 0.1408 ± 0.0023 and 0.1419 ± 0.0023 respectively. Apparently, they are both consistent with the constraint of Planck+WP dataset.

Table 2 and the lower panel of Figure 1 show the constraints with the corresponding DR9, DR11, DR11Ly α and Planck+WP datasets. When we use the $D_V(0.57)/r_s(z_d)$ measurement of SDSS DR9 in place of the Hubble parameter $H(z = 0.57)$, the tension is alleviated, this is because the measurement of $H(z = 0.57)$ of (Reid et al. 2012) includes the anisotropic information of galaxy clustering while DR9 measurement of (Anderson et al. 2012) does not. Thus the constraint on $\Omega_m h^2$ of $H(z = 0.57)$ is tighter than DR9 measurement. For a further comparison, we replace the DR9 data $D_V(0.57)/r_s(z_d) = 13.67 \pm 0.22$ with the improved measurements $D_V(0.32)/r_s(z_d) = 8.25 \pm 0.17$ and $D_V(0.57)/r_s(z_d) = 13.42 \pm 0.13$ of DR11 data, the constraint becomes a little tighter, but the tension is still alleviated when compared with the constraint by $H(z = 0.57)$ data.

An obvious feature can be seen from both Table 1 and Table 2, that is the contribution to χ^2_{min} 's is mainly

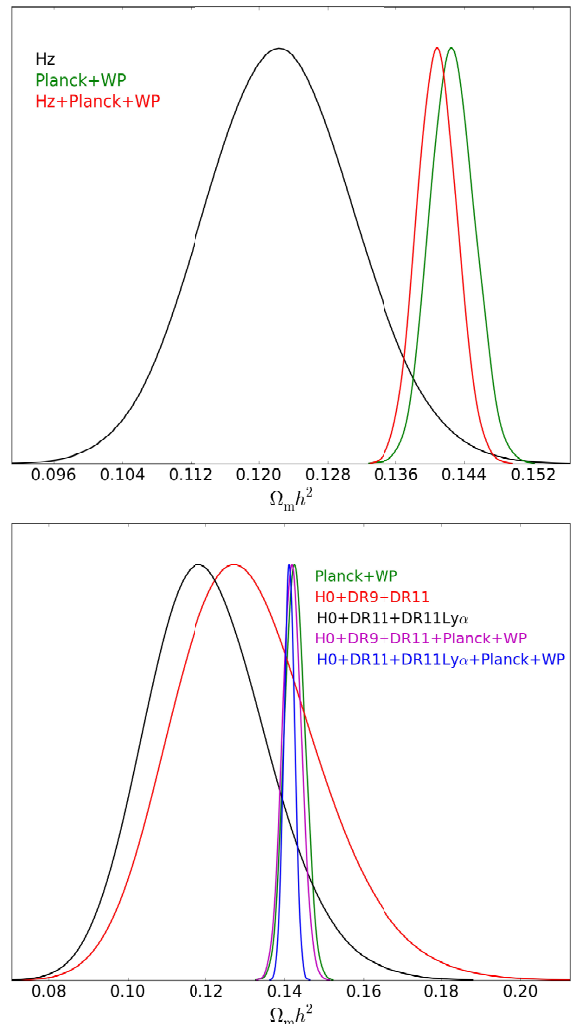


FIG. 1.— (color online). Marginalized likelihood distributions of $\Omega_m h^2$ with different datasets as masked: in the upper panel, with the Hz and Planck+WP data and their combination; in the lower panel, with the DR9, DR11 and Planck+WP data and their combinations

dominated by the Planck+WP data. These χ^2_{min} 's just change relatively small values by adding these SDSS data. The results reveal that the high-redshift BAO data is of less importance compared with the Planck+WP data on constraining the standard Λ CDM model.

For the Λ CDM model, the best-fit (black line) and 2σ constraints (filled region) of the reconstructed evolution of $H(z)$ constrained by the Hz+Planck+WP data are plotted in Figure 2 respectively. The three $H(z)$ data points with their error bars are marked as well. We find that the $H(z)$ value given by high redshift BAO data deviates from the reconstructed 2σ region of $H(z)$ constrained by the Hz+Planck+WP dataset.

We notice that there are similar features described in (Sahni et al. 2014). This is consistent with the results shown in Figure 1: the difference between the constraints by Planck+WP data and that by combining with other SDSS datasets is not much. So the constraints of $\Omega_m h^2$ are also mainly dominated by the Planck+WP data. We conclude that the significance of these high-redshift BAO data is less than that of the Planck data.

TABLE 1
FITTING RESULTS OF Λ CDM MODEL WITH THE HUBBLE PARAMETERS DATASETS .

Dataset	H z	<i>Planck</i> +WP	H0+H($z=0.57$)+ <i>Planck</i> +WP	H z + <i>Planck</i> +WP
$\Omega_m h^2$	0.1221 ± 0.0085^a	0.1426 ± 0.0025	0.1419 ± 0.0023	0.1408 ± 0.0023
χ^2_{min}	0.003	9804.166	9806.278	9810.524

^a We list the 68% CL limits.

TABLE 2
FITTING RESULTS OF THE Λ CDM MODEL WITH THE SDSS DATASETS.

Dataset	H0+DR9+DR11Ly α	H0+DR9+ <i>Planck</i> +WP	H0+DR9+DR11Ly α + <i>Planck</i> +WP	H0+DR11+DR11Ly α + <i>Planck</i> +WP
$\Omega_m h^2$	0.1305 ± 0.0179^a	0.1423 ± 0.0019	0.1419 ± 0.0023	0.1413 ± 0.0013
χ^2_{min}	0.0002	9806.092	9808.850	9811.142

^a We list the 68% CL limits.

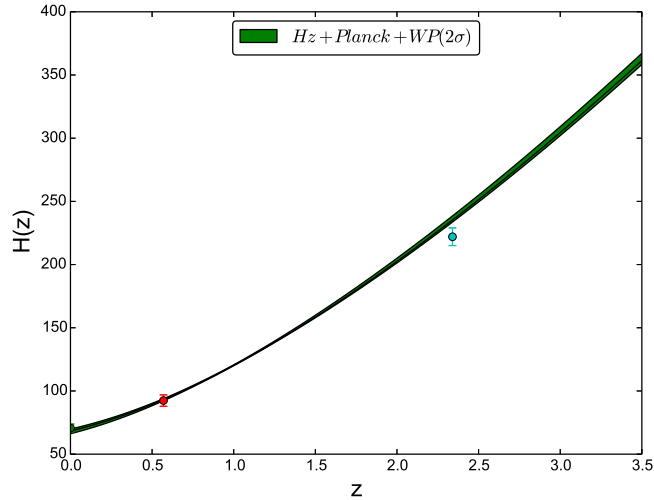


FIG. 2.— The evolution of Hubble parameter in the Λ CDM model constrained by the SDSS+Planck+WP data. The best-fit (black line) and 2σ constraints (filled region) are shown. Three $H(z)$ data points with their error bars are marked as well.

3. SUMMARY & CONCLUSION

Using only the SDSS data, the contribution to the Hubble parameter constraint is mainly dominated by the $H(z = 2.34)$ data. However, when we combine the SDSS and the Planck results, the fitting is found to be mostly influenced by the low redshift $H(z)$ data and the Planck data, so the Λ CDM model looks fine. These results indicate that the single high redshift measurement of $H(z)$ is

at variance with other data, in order to see whether dark energy does evolve, we need more independent measurements of the Hubble parameter at high redshifts.

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